

Remarks: (answer the following questions... assume any missing data... answers should be supported by sketches...etc)

Question number (1) (25 Marks)

1 (a) Choose the right answer :

1. Small signal analysis shows how a circuit appears to its dc source.
() True () False
 2. At cutoff , the JFET channel is reverse biased . () True () False
 3. For any amplifier , the lower the resistance of its load, the higher the circuit voltage gain.
() True () False
 4. In a CE amplifier the input and output current are in phase.
() True () False
 5. The voltage gain of a CE amplifier equals the ratio of the total ac collector resistance to total ac emitter resistance. () True () False
 6. PUT can be programmed to turn on at a desired anode to gate voltage level .
() True () False
 7. A load resistance connected to the drain of a common source amplifier reduces the voltage gain. () True () False
 8. The Triac is like a bidirectional SCR.
() True () False
 9. In the forward blocking region , the SCR is in the off state.
() True () False
 10. In a phototransistor ,base current is directly proportional to light .
() True () False
- (b) In Fig.1 , calculate the value of V_B that places Q_1 at the edge of active region. Assume $I_S = 6 \times 10^{-6} \text{ A}$, $V_T = 26 \text{ mV}$ and $V_A = \infty$
- (c) Determine how the transconductance of a MOSFET (operating in saturation) changes if:
- (i) W/L is doubled but I_D remains constant
 - (ii) $V_{GS} - V_{TH}$ is doubled but I_D remains constant.
 - (iii) I_D is doubled but W/L remains constant

Question number (2) (20 Marks)

- (a) Derive an expression for the drain current (triode region) and the equivalent on resistance in terms of MOSFET junction parameters.
- (b) Explain and determine the region of operation of M1 in each of the circuit shown in Fig.2. Assume $V_{TH} = 0.4\text{V}$.
- (c) For the circuit shown in Fig.3 , if the drain current = 1 mA, and the voltage gain = 0.8V, Determine R_S , V_{GS} , and W/L . Assume $\mu_n C_{ox} = 100 \mu\text{A/V}^2$, $V_{TH} = 0.5 \text{ V}$ and $V_{DD} = 1.8\text{V}$, $\lambda = 0$ and $R_G = 50 \text{ k}\Omega$.

Question number 3

- (a) Explain the operation of a light sensor.
 (b) (i) At what mode of operation is the sensor operating?
 (ii) Draw the circuit diagram of the sensor and indicate the voltage at the mode of operation.
 (c) Describe the Light sensor and its application in energizing a latching relay.

11 June 2015

Question number (4) (25 Marks)

- (a) Derive an expression for the quantum efficiency of a photodiode in the active region contribute to the measured photocurrent.
 (b) Consider radiation of wavelength $\lambda = 700 \text{ nm}$ and responsivity is 0.4 A/W . What is its quantum efficiency? If the wavelength is reduced to 500 nm , what is the new quantum efficiency if the responsivity is the same?
 (c) If we use a silicon photodetector to detect a light at 700 nm , determine the reflection coefficient of the antireflection coating. Assume the refractive index of air ($n_{\text{air}} = 1$), refractive index of silicon ($n_{\text{Si}} = 3.5$), and the reflection coefficient of the antireflection coating.

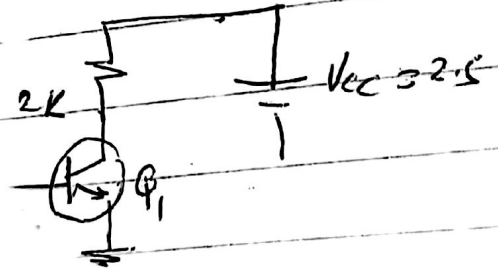


Fig.1

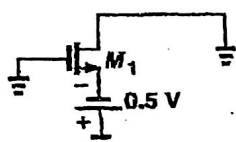
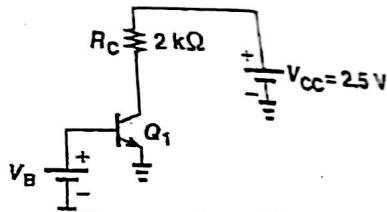
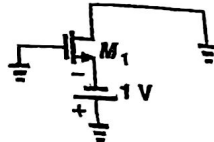
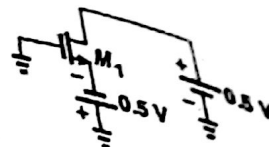


Fig.2

(a)



(b)



(c)

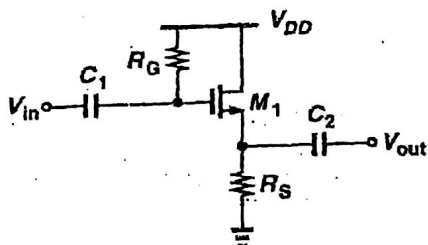
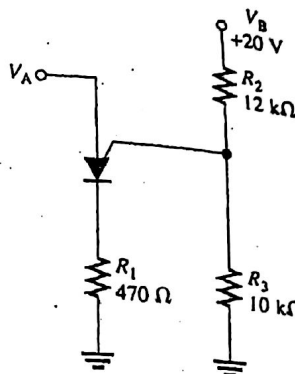
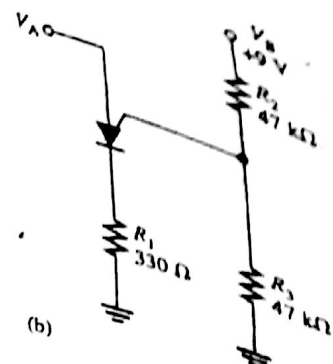


Fig.3

Fig.4



(a)



(b)

Question number (3) (20 Marks)

- (a) Explain the difference between PUT and a UJT
- (b) (i) At what anode voltage V_A will each PUT in Fig.4(a ,b) begin to conduct
- (ii) Draw the current waveform for each circuit when there is a 10V peak sinusoidal voltage at the anode. Neglect the forward voltage of the PUT.
- (c) Describe the Light activated silicon controlled rectifier , show how you can use it to energize a latching relay.

Question number (4) (25 Marks)

- (a) Derive an expression for the quantum efficiency of a photodetectors. Explain how the power transmission coefficient at the air–semiconductor interface, and the photons absorbed in the active region contribute to the measured photocurrent.
- (b) Consider radiation of wavelength $\lambda = 700 \text{ nm}$ incident on a photodetector whose measured responsivity is 0.4 A/W . What is its quantum efficiency at this wavelength? If the wavelength is reduced to 500 nm , what is the new quantum efficiency assuming that the responsivity is the same?
- (c) If we use a silicon photodetector to detect a light at 700 nm , and refractive index of air ($n_{\text{air}} = 1$), refractive index of silicon ($n_{\text{Si}} = 3.5$), determine the refractive index , thickness and the reflection coefficient of the antireflection coating. Comment on your results

Fig.1

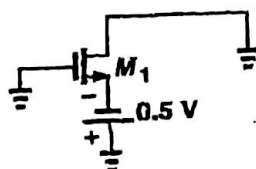
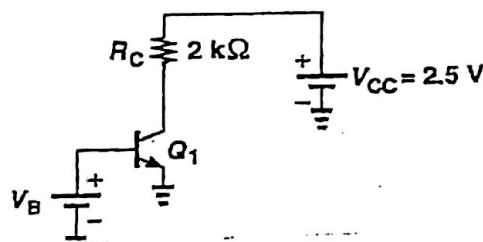
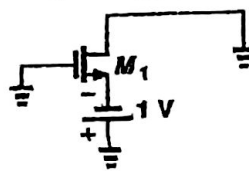
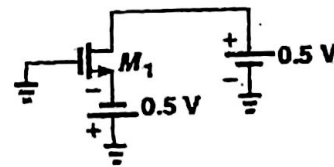


Fig.2

(a)



(b)



(c)

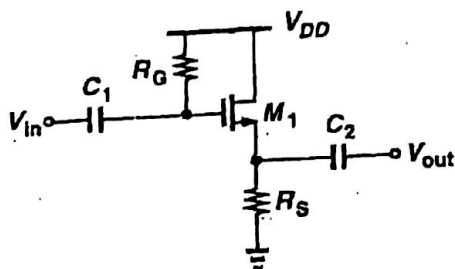
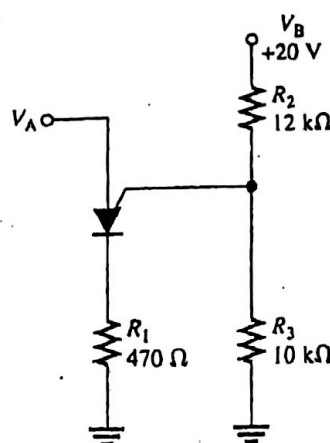
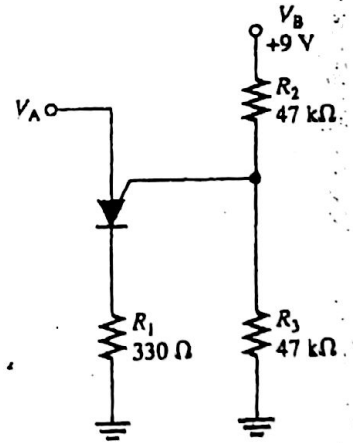


Fig.3



(a)



(b)

1(a) x x x ✓ ✓ ✓ ✓ ✓ ✓ ✓

1(b) Assume $I_S = 6 \times 10^{-16} \text{ A}$

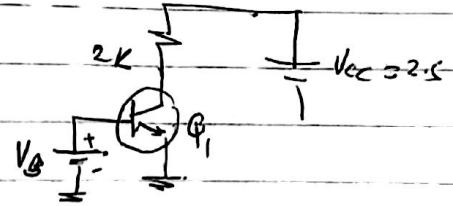
At the Active region $V_{CE} = V_{BE}$

$$V_{CE} = R_C I_C + V_{BE}$$

$$V_{CE} = R_C I_S e^{V_{BE}/V_T} + V_{BE} \quad V_{BE}/26 \text{ mV}$$

$$2.5 = 2 \times 10^3 \times 6 \times 10^{-16} \text{ A} e^{V_{BE}/26 \text{ mV}} + V_{BE}$$

$$(V_{BE} = 728.5 \text{ mV})$$



1(c) (i) $g_m = \sqrt{2 \mu_n C_{ox} \frac{W}{L} I_D}$ $I_D = \text{Const}$

Doubling (W/L) means a $\sqrt{2}$ times increase in g_m

$$g_{m \text{ new}} = \sqrt{2 \mu_n C_{ox} \left(\frac{W}{L}\right) I_D} = \sqrt{2} g_m$$

(ii) $g_m = 2 I_D / (V_{GS} - V_{TH})$ $I_D = \text{Const}$

Doubling $(V_{GS} - V_{TH})$ decreases g_m by $\frac{1}{2}$

$$g_{m \text{ new}} = \frac{2 I_D}{2(V_{GS} - V_{TH})} = \frac{1}{2} g_m$$

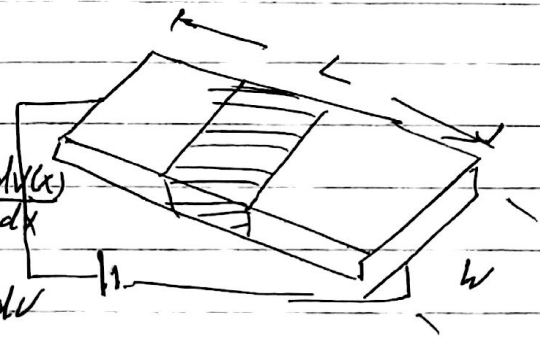
(iii) $g_m = \sqrt{2 \mu_n C_{ox} \frac{W}{L} I_D}$ $W/L = \text{Const}$

Doubling I_D increase g_m by $\sqrt{2}$ times.

Q.2 (a) $I = Q \cdot V$

$$V = -\mu_n E = \mu_n \frac{dV}{dx}$$

$$I_D = W C_{ox} [V_{GS} - V(x) - V_{TH}] \mu_n \frac{dV(x)}{dx}$$

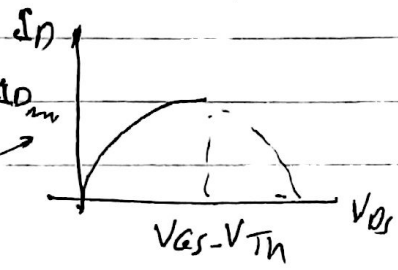


$$\int_{x=0}^{x=L} I_D \cdot dx = \int_{V(x)=0}^{V(x)=V_{DS}} \mu_n C_{ox} W [V_{GS} - V(x) - V_{TH}] dV$$

$$I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} [2(V_{GS} - V_{TH}) V_{DS} - V_{DS}^2]$$

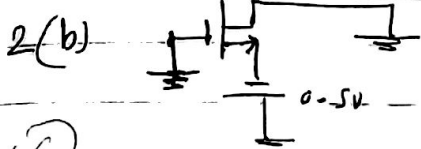
$$I_{D_{max}}$$

$$(V_{GS} - V_{TH})^2$$



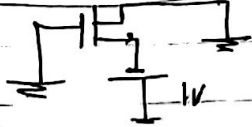
$$I_D = \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{Th}) V_{DS} \quad (2)$$

$$R_{on} = \frac{1}{\mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{Th})}$$



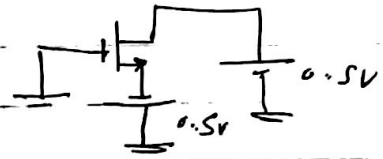
SAT

$$V_{GS} > V_{Th} \quad V_{DS} > V_{GS} - V_{Th}$$



SAT

$$V_{GS} > V_{Th} \quad V_{DS} > V_{GS} - V_{Th}$$



SAT

$$V_{GS} > V_{Th} \quad (V_{DS} > V_{GS} - V_{Th})$$

2(c)

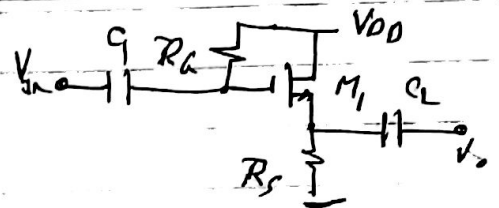
$$I_D = \frac{1}{2} \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{Th})^2$$

$$I_D R_S + V_{GS} = V_{DD}$$

$$A_V = \frac{R_S}{\frac{1}{g_m} + R_S}$$

$$A_V = \frac{R_S}{\frac{V_{GS} - V_{Th}}{2 I_D} + R_S}$$

$$= \frac{2 I_D R_S}{V_{GS} - V_{Th} + 2 I_D R_S} = \frac{2 I_D R_S}{V_{DD} - V_{Th} + I_D R_S}$$

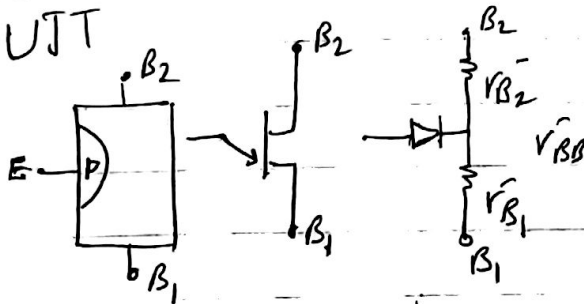


$$R_S = \frac{V_{DD} - V_{Th}}{I_D} \frac{A_V}{2 - A_V} = 867 \Omega$$

$$V_{GS} = V_{DD} - I_D R_S = V_{DD} - (V_{DD} - V_{Th}) \frac{A_V}{2 - A_V} = 0.933V$$

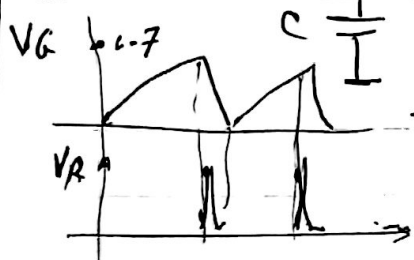
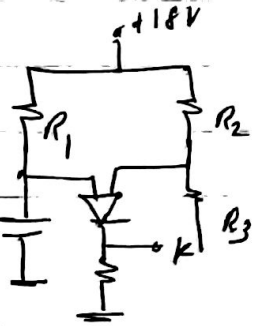
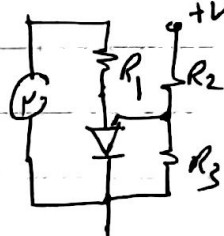
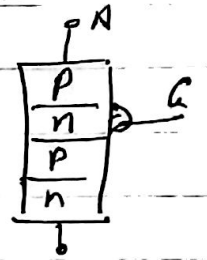
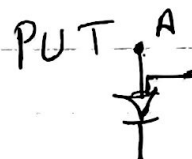
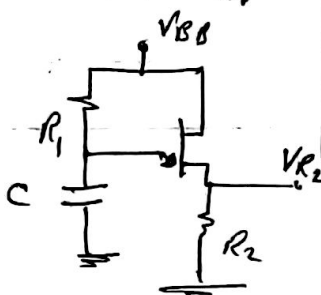
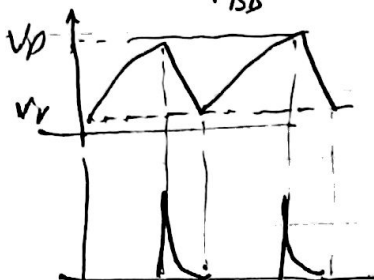
$$\therefore W/L = 107$$

3(a) UJT

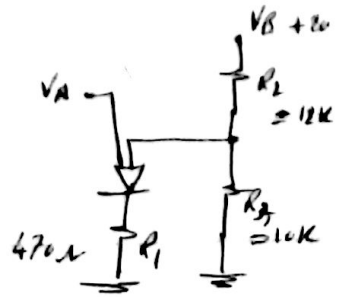


$$\tau = \frac{r_{B1}}{r_{BB}}$$

$$\frac{V_{BB} - V_P}{I_P} > R_1 > \frac{V_{BB} - V_V}{I_V}$$



3(b)

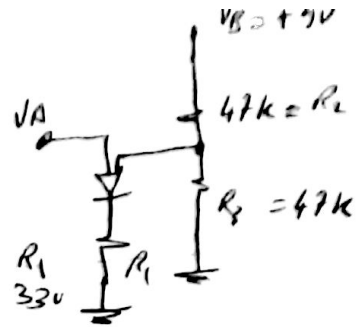
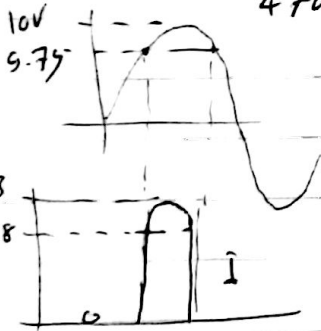


$$V_A = \left(\frac{R_3}{R_2 + R_3} \right) V_B + 0.7$$

$$= \left(\frac{10}{22} \right) 20 + 0.7 = 9.75$$

at turn on $I = \frac{9.75}{470} = 20.8 \text{ mA}$

$$I_p = \frac{10V}{470} = 21.3 \text{ mA}$$



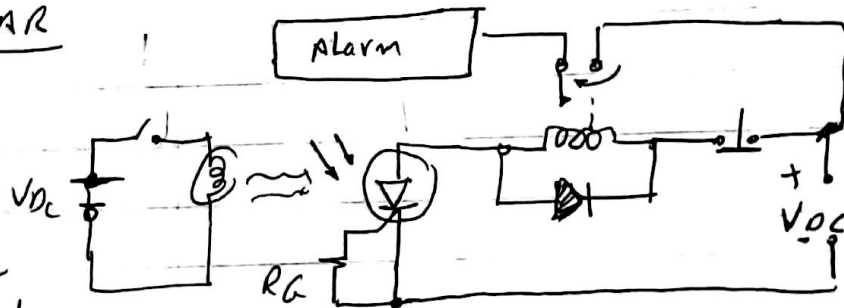
$$V_A = \left(\frac{R_3}{R_2 + R_3} \right) V_B + 0.7$$

$$= \left(\frac{47}{94} \right) 20 + 0.7 = 5.2V$$

3(c) LASCAR

(6) (6)

R_G : To reduce the sensitivity.



4(a) $\eta = \frac{\text{No of photo carriers that contribute to photo current}}{\text{No of incident photons}}$

$$N_{ph} = \frac{E}{h f_0} \quad \text{--- (2)}$$

$$\frac{N_{ph}}{T} = \frac{E}{T h f_0} = \frac{P}{h f_0} \quad \text{--- (3)}$$

$R_{incident} = \frac{P_i}{h f_0} = \text{Photons incident rate} \quad \text{--- (4)}$

Effective photo carrier generated rate $R_{gc} = \frac{E N_{pc}}{T} = \frac{I_{pc}}{q} \quad \text{--- (5)}$

(4)

From Eq 4 (Eq. 5 & 6 Eq. 1) can be written as

(6) $\eta = \frac{\text{Photo carrier generation Rate}}{\text{Photon incidence Rate}} = \frac{I_{PC}/q}{P_i/h\nu_0} = \frac{I_{PC}}{P_i} \frac{h\nu_0}{q} \cdot \frac{1}{\lambda_0}$

Note $\eta \propto \frac{1}{\lambda_0}$

$I_{PC} = qAG(w + L_e + L_h)$ --- (7)

Power transmitted at the interface

$= (1 - R_p) P_i$ --- (8)

Transmitted power through the photo diode is

$P_{tr} = (1 - R_p) P_i \exp(-\alpha w)$ --- (9)

Power absorbed in photo diode

$P_{abs} = (1 - R_p) P_i - P_{tr} = (1 - R_p) P_i [1 - \exp(-\alpha w)]$ --- 10

N. of electron hole pairs generated per unit time is

$\frac{N_{PC}}{T} = \frac{P_{abs}}{h\nu_0}$ --- (10)

$\therefore \frac{N_{PH}}{T} = \frac{E}{Th\nu_0} = \frac{P}{h\nu_0}$

$\therefore \eta = \frac{P_{abs} E}{P_i} = (1 - R_p) E [1 - \exp(-\alpha w)]$ --- 12

$(1 - R_p)$: Power transmission Coefficient

$[1 - \exp(-\alpha w)]$: Photons absorbed in active region of thickness w .

(b) $0.4 A/W = \eta \frac{\lambda_0 (\mu m)}{1.24}$ $\eta = \frac{0.4 \times 1.24}{0.7} = 0.71 = 71\%$

For $\lambda = 500 \text{ nm}$ New Q.E is $\eta = 0.71 \times \frac{0.5}{0.7} = 0.506 = 51\%$

(c) $NAR = \sqrt{n_{air} \times n_{si}} = \sqrt{1 \times 3.5} = 1.87$

$t_{AR} = \lambda / 4 NAR = 700 / (4 \times 1.87) = 93.4 \text{ nm}$

$R_p = \left[\frac{n_{si} - 1}{n_{si} + 1} \right]^2 = \left[\frac{3.5 - 1}{3.5 + 1} \right]^2 = \left[\frac{2.5}{4.5} \right]^2 = 0.3$